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BY

D. HARRINGTON AND R. G. WARNCKE

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By D. Harrington^{2/} and R. G. Warncke^{3/}

INTRODUCTION

Educational campaigns conducted by the manufacturers of explosives, the Bureau of Mines, mining companies, and safety organizations have contributed greatly in reducing accidents caused by explosives and blasting. Despite these campaigns and the dissemination of information, accidents from explosives and blasting continue to be the direct cause of scores of fatalities and hundreds of nonfatal accidents annually, not only in the mineral industry but essentially wherever explosives are used. The experience of many mining companies and other users of explosives has proved that accidents from explosives can be prevented or averted by the proper training of employees in the handling and using of explosives and by the enforcement of definite rules and instructions for their use.

Unfortunately, throughout the years numerous false impressions and ideas have grown up and around the use of explosives. Many of these can be traced back to the manner in which the users of explosives were originally taught, if instructed at all; and as with many types of misinformation in nearly all walks of life, those false ideas are decidedly persistent and being so cause much damage. Many if not most of the users of explosives gained their knowledge of explosives and blasting by watching others and more or less "absorbing" the procedures and theories of the other fellow, who acted unconsciously as teacher or instructor. A study of explosives accidents reveals the results of such "teachings" when the causes of the accidents are determined, and as might be expected the results very often are far from good. One of the most persistently erroneous impressions or ideas is concerned with the burning rate of safety fuse. Many men with

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^{2/} Chief, Health and Safety Service, Bureau of Mines, Washington, D. C.

^{3/} Mining engineer, Bureau of Mines, Washington, D. C.

years of experience in the use of explosives believe that "fuse burns a foot a minute"; this belief is one of the "hang-overs" from the teaching of many "old timers," who acquired the idea many years ago that the burning rate of all fuse was 1 foot per minute, and it has been passed on year to year by "word of mouth" to far too many present-day users.

This false idea as to the burning rate of fuse is directly responsible for many so-called premature explosives accidents, which usually have serious or even fatal results. Many accidents, supposedly or allegedly caused by "racing" or "fast" fuse, are found upon close study to be caused by "short fuse," or fundamentally to a lack of accurate information as to the burning speed of the fuse.

The fuse in commercial use today is manufactured in two standard burning rates of speed, namely, 90 seconds a yard and 120 seconds a yard or 30 seconds and 40 seconds a foot, with the latter the more generally used. The manufacturers give this burning speed with an allowable variation of 10 percent either way from the standard when burned in the open at sea level; hence, fuse of the 30-seconds-a-foot variety may burn at a speed of 27 seconds a foot or considerably less than double the erroneous figure of a foot a minute. It is apparent, therefore, that if a general rule is to be applied to the speed of burning of fuse the figure should be 2 feet a minute rather than 1 foot a minute; this would have the merit of giving a slight factor of safety to fuse burning with a speed of 40 seconds a foot and would be very close to what can be expected of the type with burning speed rated at 30 seconds a foot.

The fuse sold in the Rocky Mountain States, for use in the higher altitudes, such as Montana, Wyoming, Utah, Colorado, and New Mexico, is manufactured in Denver, Colo., at an altitude of approximately 5,000 feet, and the burning speed at the factory is rated at 126 seconds a yard or 42 seconds a foot.

Although the manufacturers of fuse give the burning rate at sea level or the factory with an allowable plus or minus of 10 percent when burned in the open, they do not guarantee the burning rate of the fuse after it leaves the factory as the fuse is subjected to many different conditions of storage, handling, and use.

The burning rate of the fuse is more or less affected by many factors such as the conditions of storage, weather, method and character of tamping, difference of altitude, mishandling, and possibly other factors.

It is fully as important to have suitable conditions for storage of fuse as for explosives. Exposure to excessive heat for a short time is

sufficient to retard the burning rate of the fuse, and fuse that has been overheated only to a point that the powder train has become partly saturated with the waterproofing of the fuse is likely to be affected with irregular burning, both as to speed and as to efficiency.

Storage in a damp place also retards the burning rate of the fuse. As underground air ordinarily is humid, it is unwise to store fuse underground unless a suitably heated place is provided. The waterproofing of fuse is fairly effective in keeping water out, and the drying of fuse that has been wetted is difficult. Even after wet fuse has been dried, the burning rate is likely to be altered and irregular; experiments show that fuse that has been stored in a very damp place may vary in burning speed from 10 to 45 percent from normal.

The rate of burning speed in the confinement of a borehole may vary owing to the many kinds of material used in stemming and the different degrees of tightness of the tamping procedure. The greater the confinement of fuse in the hole by the stemming, the faster the burning speed of fuse is likely to be; this is another good reason to consider that the burning rate of fuse is more likely to be 2 feet a minute than 1 foot a minute, the error in so doing being likely to be on the side of safety.

Increase in altitude has the effect of retarding or slowing the burning rate of fuse; this is due to the lower external pressure on the fuse and is the opposite of the effect when the external pressure is greater as caused by confinement in a borehole by ramming. In general, however, fuse sold for use in the higher altitudes in the United States is manufactured in Denver, Colo., and has a definite burning rate (about 42 seconds a foot) at altitudes 5,000 feet above sea level.

Mishandling or mechanical injury to fuse, such as being struck a blow or stored with excessive weight on the fuse, may accelerate the burning rate, while storage for an excessive period will be likely to retard the rate, as might happen if the older stock is not used before that received more recently.

This possible acceleration and retardation of the burning rate of fuse should be borne in mind by all users of fuse. The variations caused by the conditions mentioned will in most instances be covered by the allowable 10 percent above or below the standards of the manufacturer, but this matter is seldom considered by the user. These variations undoubtedly explain some of the cases of so-called "running" or "racing" fuses, although the main causes are that the user is not aware of the standard burning speed or ignores it, or, for some reasons of his own, he deliberately resorts to short fusing.

Many mining companies, quarry companies, and large contractors post the burning rate of fuse where all their employees can see it; in addition to posting the burning rate, many companies suggest that their employees burn one or preferably several lengths of fuse to determine the rate of burning of the fuse in the place and as nearly as possible under the conditions to which it is subjected. The suggestion has been published by many agricultural papers and magazines that occasional users of fuse make such a test before using it. The explosives companies selling fuse endeavor to spread this type of information as much as possible, but even so the efforts of all who are trying to keep such information before people who need it do not seem to be enough, inasmuch as far too many accidents occur due to lack of attention to this one detail.

The following samples illustrate accidents caused apparently by lack of knowledge of the burning rate of the fuse and instances of short fusing which might have been the **result** of not knowing the burning rate of fuse. These are by no means all of the instances that can be given.

EXAMPLES OF ACCIDENTS WITH FUSE

Texas Mercury Mine - 1943

Two men were killed in a blasting accident while spitting the fuse in a shaft they were sinking. The shaft, 350 feet deep, was being sunk deeper, and the safety station for use of the shaft men was on the 300-foot level; the men climbed a ladder to this station after spitting the fuse.

The foreman stated that on the day of the accident 19 holes had been drilled and each loaded with four sticks of dynamite. Normally 6-foot fuse was used, and "this meant that 6 minutes would be used to set off the dynamite, as the fuse burns a foot a minute." The miners experienced some trouble lighting the fuse. The foreman, who was waiting about 8 feet above on the ladder timing the fuse, observed that 4 minutes had elapsed and shouted to the men to come up as only 2 minutes remained. One of the men replied that they had plenty of time, and although the foreman shouted several times and started up the ladder, the miners did not follow. The shots went off and killed both miners.

The foreman stated that he had been employed in this type of work and handling dynamite in mines and shafts since 1919 and had always followed this procedure in firing holes.

Remarks:

This accident was a direct result of not knowing the burning rate of the fuse. The foreman had been using explosives for years, always under

the impression that "it burned a foot a minute." He believed that after 4 minutes had elapsed there was a "cushion" of 2 minutes for escape. This is typical of many explosives accidents, in that the "wrong thing" can be done many times under favorable conditions without mishap; but eventually the law of averages prevails, with the result that fatalities or disaster follows. The fuse in this case performed according to the standard of 40 seconds per foot fuse, as it burned 6 feet in about 240 seconds or 4 minutes.

Colorado Well

A man was seriously injured in June 1943 while attempting to blast the corroded and blocked 6-inch casing of a 23-foot sewerage water-disposal well in a small Colorado town.

To blast the obstruction in the pipe, the victim was attempting to place a stick of 40-percent dynamite with a capped fuse 2 feet long in the casing of the well. He lighted the fuse and pushed it into the casing, using a 2-by 2-inch stick of wood 5 feet long as a tamping stick. After several unsuccessful attempts to place the dynamite in the proper position, he pulled the dynamite cartridge from the hole and started to pull the capped fuse from it when it exploded in his hands. The injuries included loss of the left hand and part of the forearm, lacerations of the face, punctured wounds, and injury to the left eye that may result in loss of 90 percent of the vision.

The owner was present when the accident occurred and stated he shouted to the man to throw the explosive away, but he replied that he knew he had plenty of time as he had a 20-minute fuse.

The injured man claimed to have used explosives for approximately 40 years in the irrigation districts, but the work was confined to shooting occasional adobe shots and holes in rock to obtain riprapping for irrigation ditches.

Remarks:

This accident was due entirely to inexperience in using explosives and lack of anything like accurate knowledge of the burning rate of fuse. This man evidently had little, if any, real experience in handling explosives; certainly his ideas of the characteristics of fuse were extremely vague, as it is very improbable that any fuse has ever been manufactured and known as a "20-minute fuse."

Western Manganese Mine - 1944

Two men were killed while igniting the fuse of a round of eight shots in the face of a drift in this mine.

The round consisted of two rows of holes from the bottom to the top and consisted of "down-cuts", "breasts", "backholes" and "lifters"; and they were to be fired in the order named. All the holes were double-primed and at the time of the loading water was flowing from all holes. Sixteen capped fuses 7 feet in length were delivered to the miners shortly before the accident.

An investigation of the accident disclosed that one backhole missed, and the evidence pointed to abandonment of the other backhole by the miners owing to the flow of water. When the broken rock was cleaned up it was found that one lifter hole, which was double-primed with the fuse protruding about 31 inches from the collar of the hole, had not been spit, although the ends were split and the one fuse was cut 2 inches from the split end. An open fuse knife was recovered in the muck pile at a point where the body of the miner, who was spitting the fuse, was found. Several pieces of cut fuse ranging in length from $4 \frac{9}{16}$ to $11 \frac{11}{16}$ inches were found in the muck pile, indicating that some pieces of fuse used in this round were only about 6 feet long.

All evidence gathered seem to indicate that the miners were in a stooping position attempting to light the lifter holes when the cut holes exploded.

The Bureau investigators tested a length of fuse from the reel of the fuse used and found the burning rate to be about 43 seconds a foot, the manufacturers' rate for this fuse being 42 seconds a foot. The State official investigating this accident, in testing the fuse for the burning speed determined a considerably slower rate and thought it was all right; however, it is probable that the timing was at fault when the test was made. He apparently believed that fuse burns a foot a minute instead of at the rate of about 42 seconds a foot.

Remarks:

This was an avoidable accident, as proper precautions were not taken while blasting in a wet place. The miners remained in the place too long attempting to light the wet fuse, and they apparently had no accurate knowledge of the burning rate of the fuse or they would not have remained in the place attempting to light all the fuse. Unquestionably, these men believed that fuse burned at a rate of about a foot a minute.

Kingman, Ariz. - 1940

In the following instance, a fatality or a serious accident was probably averted by the prompt action of a miner who was on the platform watching another miner spit some fuse.

Two miners were sinking a shaft for sampling. The shaft about 80 feet deep, had a platform on the 50-foot level, and was untimbered above the platform. Access to the bottom of the shaft from the platform was by rings nailed to the bucket guides which served as a ladder to about 14 feet below the platform, and then a ladder was used which was controlled by a rope from the platform.

The two miners had drilled and charged eleven 3-foot holes; one of them remained to spit the round, and the other went to the platform to handle the ladder. The miner remaining below ignited the fuses, which were single-taped and not trimmed for timing; after retrieving his knife he started for the ladder just as the next to the last hole went off.

The concussion extinguished both miners' lights, and the miner on the bottom was peppered about the body with fine rock and splashed in the face with muddy water. After the explosion the miner on the platform set the ladder down and immediately descended the shaft and helped the injured man to the 50-foot level, where both took refuge in a short drift until the rest of the round went off.

The miners attribute the premature blast to "running" fuse.

Remarks:

It seems unlikely that a "running" fuse was responsible for the accident, inasmuch as it came from the same supply as was used in the remaining holes. As it was the next to the last fuse spit that went off and the fuse was not cut for timing, a short fuse may have been inserted in some manner and the miners probably had no adequate or accurate knowledge of its burning rate. The accident could have been caused by carelessness in lighting the fuse, and the method of spitting could have been at fault; but in any event it is almost a certainty that the miners in this case also relied upon the 1-foot-a-minute burning rate for fuse, which again caused an accident.

Arizona Metal Mine

A blasting accident at the face of the 500-foot level in an Arizona metal mine, about 95 feet from the shaft, resulted in the death of one man and injury to another.

In this mine all underground men used electric cap lamps, and electric detonators were used only in shaft sinking. All other blasting was done with fuse cut in 7-foot lengths, purchased in lots of 9,000 feet, which constitutes about a 10- to 12-day supply.

Usually 16 to 18 holes were used in regular rounds, but in this instance 24 holes were being shot. Two miners drilled and charged 24 holes; one miner lighted all the fuses on the left side of the cut-out, and just as both started to leave a shot on the left side detonated. The miner who spit the fuses on the left side was in the rear and received the full charge. The miner in the lead was more or less protected by an offset on the left wall of the drift and was hit in the back with flying rock but not seriously injured; he was able to run to the 500-foot level station.

The survivor testified at the inquest that the accident was caused by defective fuse but later stated that the victim was too slow and that he had warned him about staying in the face too long. The deputy State inspector believed that the fuses were too short. The superintendent was said to have found several pieces of fuse, one of which was 20 inches in length, in the muck pile.

Remarks:

It is apparent from the above that the miners cut the fuse too short for spitting 24 holes. When 20 inches was cut from a 7-foot length of fuse (using 40-seconds-a-foot fuse) only 3 1/2 minutes was allowed from the time the fuse was spit until the charge should detonate; it is obvious that the miners did not know the burning rate of the fuse and cut the fuse much too short.

Kansas Lead-Zinc Mine - 1944

Two miners were injured when one of a number of "boulder pops" they were spitting detonated prematurely. Both injured men will lose the vision of one eye, and one of them may be totally blind in both eyes.

The accident occurred on a bench about 20 feet high, the top of which was on the 300-foot level. The bench, which was about 75 feet long, had been blasted previously, but on the day of the accident the miners had drilled and loaded 20 holes in large boulders on the sloping ore along the full length of the pile.

In loading the holes the miners used capped fuse, which they secured at the "shot house" and which had been made up and placed there by the blasting crew. The fuse was in 4 1/2-foot lengths and was the 40-second a-foot type. In loading "boulder pops" a half stick of explosive is gener-

used; if more is needed, the wrapping on other sticks of explosives is cut, and the needed quantity of explosives pressed into the hole over the primer. No tamping or stemming is used when boulders are blasted.

The two miners, using pieces of fuse as "spitters," started spitting the fuse at the opposite ends of the pile, working toward the center. When they met at the center, one of them reached to spit the last fuse, and it is said to have spit out a flame about a foot long followed by an explosion. The foreman, who was about 200 feet away, heard the men call for help and led them both to safety. They were halfway to the surface before the other shots went off.

The injured men stated that they did not cut the fuse and indicate that the fuse might have been defective; the foreman also held this view. However, three pieces of fuse from the same stock were taken to the surface and timed, and they burned at the rate of 43, 46, and 47 seconds a foot, respectively.

Remarks:

Although this fuse may have been defective, it is more probable that there was carelessness in spitting the last fuse, and there was no stemming in the hole. Owing to the lack of definite information the possibility of short fuse should also be considered as the cause, for it was the last hole spit that detonated.

SUMMARY AND CONCLUSIONS

The examples given above are only a few of the many accidents caused by not knowing the burning rate of fuse, by the erroneous impression that fuse burns a foot a minute, and by the use of short fuse - generally the result of lack of knowledge of the burning rate of the fuse in use. These accidents indicate the necessity of all the users of the fuse knowing the burning rate of the fuse being used; this can be accomplished by posting the burning rate of the fuse in conspicuous places, where it will be seen by all users; in addition, the users should be urged to burn one or more lengths of fuse and time it carefully to determine the burning rate of fuse. This should be done, so far as feasible, in the place and under the conditions to which it is subjected when blasting.

Many of these accidents result from poor supervision and lack of definite instruction to the miner; closer supervision of blasting practices and more definite instructions by the supervisory force should aid greatly in reducing these accidents. The management should designate a minimum length of fuse to be used, and this should be of sufficient length to provide a safety factor for the men lighting the fuse.

Delaying too long at the face causes many of these accidents, generally fatalities, owing to difficulty in spitting by damp or wet fuse; this is under the control of the miner or the man spitting the round and can be prevented by using a signal or warning fuse, or what is known as a "time" which is a piece of fuse much shorter than the shortest fuse in use in the blasting holes and when burned warns the miners to leave. In some surface work the fuse can have a detonator attached, or a fire cracker-type signal as a warning. All these warnings, if correctly planned and manipulated, will give the "blaster" enough time to leave the place before the first shot detonates, and the warning should be heeded even though it may cause spoiling the round.

All the accidents in the above examples probably could have been prevented by the use of electric detonators, especially in wet places; however, if safe practices had been followed they might not have occurred with the use of fuse.

Accidents due to short fusing or to mistakes as to the rate of burning of fuse generally result in fatalities or serious injuries; they can be eliminated by educating the users of fuse to remember that the average burning rate of fuse is 30 or 40 seconds a foot. A good rule-of-thumb is to allow 2 feet a minute and not 1 foot a minute and to remember that mishandling, improper storage, and the use of certain procedures in stemming and tamping more or less affect the burning rate. To be on the safe side, therefore, assume that any fuse may burn at a rate of 2 feet a minute; even then the factor of safety is by no means large.